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Validity and limitations of the Three Plane Compton Imaging Technique via Simulations

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Abstract

Gamma imaging based on Compton scattering was first proposed approximately 20 years ago[1,2] as a replacement for mechanically collimated imaging systems[3,4]. The advantages of such instruments over mechanically collimated systems are a wider field of view, higher efficiency (more source photons are used in the image construction), source localization, use in high-background environments, and non-tomographic three-dimensional imaging[5] of near-field sources. One can also image multi-energy photons by selecting events based on the summed energy deposited in multiple detectors. The traditional example of such imaging systems is Compton camera. Until recently, limitations with associated hardware have resulted in Compton imaging seeing few applications. However, with advances in high spatial resolution detectors, and further developments in the physical principles there has been a renewed interest in gamma imaging based on Compton scattering in many areas including astronomy and nuclear medicine. In this paper we present an evaluation of a new concept first proposed by J.D. Kurfess et. al[6], referred in this paper as the three plane Compton imaging. Such technique if valid could lead to many useful applications.

Summary:

A traditional Compton camera uses the Compton scattering process in two or more position sensitive gamma-ray detectors to reconstruct the direction and energy of the incident photons. The cone axis is determined by location of the gamma ray interactions in the detectors. A large number of scattering events from a given source of gamma rays define multiple cones, which intersect at the location of the source. The image reconstruction technique can then be used to superimpose these cones resulting in a peak, which uniquely determines the location of the source. These traditional Compton telescopes employ a low-Z scintillator in a scatter plane and a high-Z scintillator in an absorber plane. Such instruments often have an efficiency of ~1% or less due to severe background and track reconstruction problems.

To increase the efficiency of Compton imaging techniques new physics concepts are being proposed. One such concept called here as a three plane Compton imaging technique was first proposed by J.D. Kurfess et. al[6]. This concept (Figure 1) requires two successive Compton scatter interactions followed by a third interaction all in detectors with high position and energy resolution. In Figure 1, E1, E2 and E3 are the incident photon energies for each interaction. The measured energy losses in each interaction are

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[1] D. Herzo et al., Nuclear Instrumentation And Methods,123 (1975) 583.

[2] V. Schonfelder et al., IEEE Trans. Nucl. Sci., NS_31 (1984) 766.

[3] M. Singh, Med. Phys. 10 (1983) 421.

[4] J. B. Martin et al., IEEE Trans. Nucl. Sci. NS-41 (1994) 1221.

[5] King et. Al., Nuclear Instrumentation And Methods, A 353 (1994) 320-323.

[6] J. D. Kurfess, W. N. Johnson, R. A. Kroeger, and B. F. Philips, “Considerations for the Next Compton Telescope Mission.”

respectively L1, L2 and L3 and the Compton scatter angles for gamma-rays are $\phi 1$ and $\phi 2$. The two Compton equations then are,

$$COS(\phi 1) = 1 - mc^2[(1/E2)-(1/E1)] \quad (1)$$

$$COS(\phi 2) = 1 - mc^2[(1/E3)-(1/E2)] \quad (2)$$

$$L1=E1-E2 \quad (3)$$

$$L2=E2-E3 \quad (4)$$

The angle $\phi 2$ is determined from the measured location of interactions. Solving for E1 in terms of measured quantities $\phi 2$, L1 and L2 we get,

$$E1=L1 + (L2/2)+0.5[L2^2+(4mc^2 L2/(1-COS(\phi 2)))]^{0.5} \quad (5)$$

Using the calculated value of E1, measured value of L1 and equation (1) the direction cone can be determined. With this concept Kurfess et. al. claim that one should be able to obtain efficiencies as high as 25-50% in the MeV region. In this approach background events will be discarded as the re-construction of background events will not lead to a valid Compton scattering sequences.

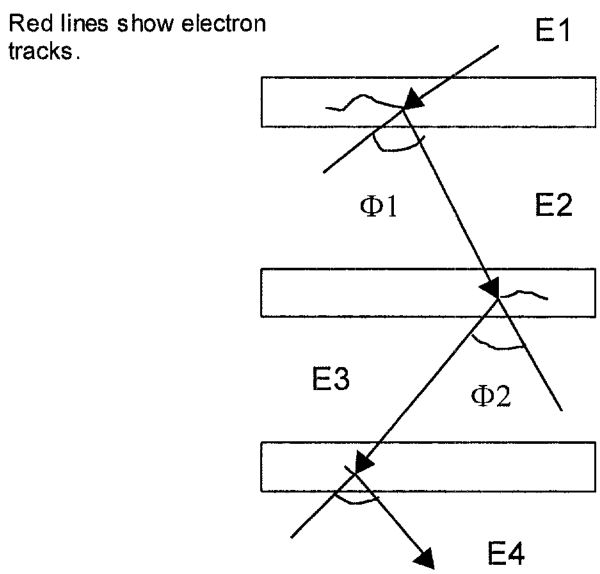

Figure 1: Schematic Diagram of the Three plane Compton Imaging Technique.

We at LANL are performing simulations to study validity and limitations of such a technique using GEANT[7] Monte-Carlo package. In addition to this we are writing tracking routines to complement the simulations. In this paper we will present the results

[7] "GEANT: Detector Description and Simulation Tool," **CERN Program Library Long Writeup W5013**

of our simulation studies for gamma ray energies from few-keV to 4 MeV. We will also explore limitations if any of such a technique via our simulation studies.